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Research and analysis of the efficiency fiber-optic communication lines using DWDM technologies

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Abstract

The performance indicators fiber-optic communication lines using spectral technology with separation communication channels are analyzed. The effectiveness of the use network resources optical telecommunication systems using spectral technologies based on the architectural concept of the next NGN (NGN, Next Generation Network) and future FN (FN, Future Network) networks has been studied. This work is devoted to the construction methods for calculating the indicators optical networks and the study methods and tools for improving the efficiency using network and channel resources fiber-optic communication lines using dense spectral multiplexing optical signals with separation communication channels.

The problem ensuring effective management channel and network resources in optical communication networks are considered. As a result of the study technology spectral multiplexing, a new approach to the construction of a calculation method is proposed that describes the efficiency managing network and channel resources in fiber-optic communication lines, taking into account the numerous requirements their parameters and transfer characteristics. On the basis of the calculation method, analytical expressions are obtained that allow estimating the resources of the system, indicators informational and spectral efficiency of the functioning fiber-optic communication lines.

The results of the research can be applied by cellular operators when designing an optical telecommunications network, in particular, to determine the optimal value of the capacity optical systems based on wavelength multiplexing technology and modulation spectral efficiencies.

Keywords: throughput, spectral efficiency, fiber-optic communication lines, bit rate, advanced optical technology, OSNR, wavelength, DWDM systems, channel resource

Introduction

At present, multi-service telecommunication systems and communication networks, as well as their telecommunications industry, are developing an unprecedented change associated with the transition from the NGN concept to the future FN architectural concepts. This is a consequence of the rapid development optical, quantum and digital end-to-end technologies and a variety network applications.[1,2] Therefore, one of the main requirements for fiber optic communication lines and optical networks is the ability to quickly increase the number communication channels and the bandwidth broadband multichannel systems in accordance with the growth in the amount heterogeneous traffic transmitted.[3,4] The conducted studies and analysis showed [2,5-7] that one of the main advantages of the technology spectral channel separation of optical systems operating in the multi-user spectral wave mode is the possibility organizing broadband multi-channel communication systems with efficient use of network resources.

To ensure the effective functioning optical information transmission systems, it is necessary to choose the optimal strategy for the maintenance fiber-optic communication lines using spectral technology [6, 8, 9, 10]. These include the following information fiber optic technologies WDM/DWDM and HDWDM (Wavelength Division Multiplexing/Dense WDM & High Dense WDM) with wavelength $\lambda_i = 0.85,...,1.55\,mkm$. For fiber-optic communication lines, the main element which are receiving optical modules, fiber-optic cables and transmitting optical modules.[8-10]

Thus, this work is devoted to the study of methods and means increasing the efficiency using network resources fiber-optic communication lines using dense spectral multiplexing of optical signals with separation communication channels.

General statement of the problem

In this case, for the efficient use network resources in an optics system, the task is to be able to transmit a large amount messages to several communication channels simultaneously due to the formation of several parallel data streams, which can significantly increase the throughput optical telecommunication systems using fiber optic communication lines. In this case, the information and spectral efficiency can be additionally increased by using various dynamic strategies for organizing broadband communication channels that take into account the current state of the optical systems.[2,6–10]

The rapid development fiber-optic communication lines based on wavelength multiplexing for regular expansion of the range multimedia services and applications provided to subscribers leads to the fact that optical communication companies have to operate a significant number heterogeneous communication channels and terminal equipment.[3,9,10]

This raises the problem managing network and channel resources and their most efficient distribution in the nodes of the communication network to provide various services to different groups users, taking into account numerous parameters.

Based on,[2,3,6–10] the coefficient of effective use network and channel resources fiber-optic communication lines $R_N(\lambda_i, N_k)$ when using spectral technologies is as follows:

$$R_N(\lambda_i, N_k) = R_k(N_k, \lambda_i) + R_n[\eta_{SE}(\lambda_i)]\,,\ i = \overline{1,n} \qquad (1)$$

where $R_k(N_k, \lambda_i), R_n[\eta_{SE}(\lambda_i)]$ – accordingly, the coefficient of effective use of channel and network resources fiber-optic communication lines when using spectral technology and the DWDM system, taking into account the number channels, spectral efficiencies and wavelength λ_i, $i = \overline{1,n}$.

Expressions (1) provide a guarantor in order to increase the maximum throughput value for trunk channels and the transmission range of the system, which functional dependencies are described as follows:

$$R_N(\lambda_i, L_{\max}, N_k) = \mathrm{W}[\mathrm{C}_{\max}(\mathrm{N}_k, \lambda_i)], \ i = \overline{1,n}, \quad (2)$$

where $\mathrm{C}_{\max}(\mathrm{N}_k, \lambda_i)$- the maximum value of the bandwidth of optical communication channels, taking into account the number of channels N_k and wavelength λ_i, $i = \overline{1,n}$; $L_{\max}$ – maximum transmission distance optical systems.

Taking into account the above assumptions, the statement of the problem is investigated and a new approach to its solution is proposed.

Terminal equipment DWDM systems

It is worth noting that the reason for the emergence of this problem lies in the fact that at present, issues related to the analysis of the quality of operation of optical networks using WDM and DWDM technologies have acquired considerable importance. By itself, WDM and DWDM technologies have the necessary mechanisms to ensure high throughput, security, transmission reliability and message delivery assurance.[2,3,10,11]

In addition, a key advantage WDM and DWDM is that it is protocol and bit rate independent. Optical networks based on DWDM can transmit data in IP (IP, Internet Protocol), ATM (ATM, Asynchronous Transfer Mode), SDH (SDH, Synchronous Digital Hierarchy), SONET (SONET, Synchronous Optical Network), and Ethernet.[2, 5–10]. Thus, DWDM-based optical networks can transmit different types of traffic at different rates over an optical channel. Voice, e-mail, video and multimedia transmissions are just some examples of services that can be simultaneously transmitted in WDM and DWDM systems.

DWDM systems have channels at wavelengths spaced apart $0.0004\,mkm$ (50 GHz) or $0.0008\,mkm$ (100 GHz). DWDM systems have channels at wavelengths located at a distance DWDM system usually consists of five components: optical transmitters / receivers, DWDM Mux / DMux filters, Optical Add / Drop Multiplexers (OADMs - Optical Add-Drop Multiplexer), optical amplifiers, transponders - wavelength converters. DWDM transponders of the latest generation make it possible to build the most balanced solution between the throughput and transmission range of the system.[2,5–8] These devices are the terminal equipment of the DWDM system - the technology dense spectral multiplexing.

Now, let's look at the important devices - transponders and muxponders in a general way, and then explain the difference between them. Both devices transmit a linear signal at the desired wavelength within the selected WDM and DWDM format.[5–10]

The components in the transmitting part (lasers and modulators), as well as forward error correction algorithms, ensure its sufficient resistance to noise and distortion.

The use of modern modulation formats in transponder/muxponder units makes it possible to provide high network throughput.[2,10,11] On the other hand, transceiver modules provide a transparent transformation various client interfaces into a linear one with monitoring and error control capabilities. To evaluate the effectiveness such strategies, adequate methods for calculating the network and channel resources optical telecommunication systems using the technology multiplexing optical channels by wavelength are required.

To solve this problem, in addition to the above, we consider the network and channel resources fiber-optic communication lines using the technology of multiplexing optical channels by wavelength.[5,10,11] Here, as an indirect task, from the point of view of the information aspect, is the possibility transmitting data streams, both useful and service, to several users simultaneously due to the formation of several parallel communication channels.

This raises the requirement to create distributed multichannel communication systems as optical message transmission systems with increased bandwidth using WDM and DWDM technology.

Descriptions DWDM system calculation methods

Currently, the task increasing the throughput modern fiber-optic communication systems remains relevant, since the number channels and users is constantly growing and the volume transmitted streaming data is increasing. In contrast to the extensive approach increasing the number broadband multichannel systems, which is not always beneficial from an economic point view. However, perhaps from a technical point view, one of the effective approaches is the use WDM and DWDM multichannel transmission technology.[2,3,5]

The main difference between this optical technology and classical information, network and computer technologies is the use of several communication systems both on the transmitting and receiving sides.[2,3]

A more detailed description features of the functioning this system will be given below. Nevertheless, despite the increase in data transmission speed over communication channels provided by the use DWDM technology itself, it is possible to achieve better system capacity and user throughput in such telecommunication systems through the use effective strategies for organizing multichannel communications.[2,3,5–10]

In particular, in the article,[6,8–10] several variants of strategies for the information and network resource distribution scheduler were proposed in both single-user and multi-user modes.

The authors built a mathematical model of the DWDM system in the form of a system for calculating the transfer characteristics in continuous time under the conditions each of the proposed strategies. And conclusions are drawn and recommendations are given regarding the effectiveness of a particular strategy and methods based on numerical experiments of the capacity of the DWDM system.[2,3,10,11]

Creation noise-resistant fiber-optic communication lines with increased bandwidth, operating via digital optical communication channels with the introduction spectral technologies, will help increase the reliability digital information reception.

In modern fiber-optic communication lines using spectral technologies, the reliability of the transmission digital optical signals and the probability of a bit error for a given interference are mainly determined $N_n(t)$, which are described in the form objective functions as follows:

$$Q_{EF.}(\lambda_i) = W[\max_{\lambda_i} R_N(\lambda_i, N_k)], i = \overline{1,n}, \quad (3)$$

under the following restrictions

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$$OSNR(\lambda_i) \ge OSNR_{i.}(\lambda_i), V_b(\lambda_i) \ge V(\lambda_i), \quad C(\lambda_i) \le C_{an.}(\lambda_i), i = \overline{1,n} \tag{4}$$

where $R_N(\lambda_i, N_k)$ – coefficient of effective use network resources fiber-optic communication lines when using spectral technologies, taking into account the number channels N_k and wavelength λ_i, $i = \overline{1,n}$; $V_b(\lambda_i)$ – bit rate of optical signal transmission over fiber-optic communication lines; $C_{an}(\lambda_i)$ – cost of optical signal transmission lines and fiber-optic communication lines hardware and software using fiber optic cable, receiving and transmitting optical modules; $SNR_{out.}(E_b, \lambda_i, N_0)$ – optical signal-to-noise ratio at the fiber-optic communication lines output, $OSNR$ (Optical Signal to Noise Rate) taking into account the bit signal energy E_b and the noise power spectral density N_0, which characterize the system resources and complex indicators communication quality when using the wavelength λ_i and is expressed as follows:

$$SNR_{out.}(E_b, \lambda_i, N_0) = OSNR_T(P_S) + \Delta\alpha_Z, \ i = \overline{1,n}, \tag{5}$$

where $OSNR_T(P_S)$ – the value $OSNR$ required by the receiver to receive a signal with an error P_{BER} rate not exceeding some given level $P_{BER} = (10^{-10}, ..., 10^{-12}) \le P_{BER}^{all.}$; $\Delta\alpha_Z$ – safety factor [2, 3, 5] is usually taken within, 3,…,5 dB.

Expressions (1), (2), (3), (4) and (5) describe the essence of the new approach under consideration, taking into account the complex indicators fiber-optic communication lines, on the basis of which a method for calculating the noise immunity of optical signal reception is proposed.

In addition, expressions (1), (2), (3), (4) and (5) determine the possibilities of the method for calculating the noise immunity indicators fiber-optic communication lines taking into account the transfer characteristics of fiber-optic communication lines based on spectral technologies and are a simple analytical record of the reliability function optical systems when assessing their quality of operation.

In order to fulfill the objective function (3) for the noise immunity of the fiber-optic communication lines operation and their specified restrictions (4) and (5), it is necessary to investigate:

- Methods for receiving optical signals multimedia traffic;
- Methods for implementing optical signal-code structures;
- Methods for increasing the optical signal-to-noise ratio $OSNR(E_b, \lambda_i, N_0)$ at the receiver input;
- Efficient error correction decoding algorithms and circuit solutions of receiving optical modules.

Research and evaluation spectral efficiency of the system

The operation algorithm of the WDM and DWDM system is based on wavelength multiplexing technology and is based on the fact that one fiber can transmit optical signals at many wavelengths.[5,6,10,11] At the same time, the capacity optical lines $E(t, \lambda_i)$ can be increased by increasing both the bit rate $V_b(t, \lambda_i)$ and the number channels of the DWDM system, which is expressed as follows:

$$E_c(t, \lambda_i) = N_k \cdot V_b(t, \lambda_i), \ i = \overline{1,n}, \tag{6}$$

Using optical WDM and DWDM technology, let's consider the analysis and research of the dependence transmission speed on the signal-to-impedance ratio, which is a quality indicator optical telecommunication systems, in communication channels organized by the multiplexing method. For this, first of all, let's look at the indicators of the studied system.

According to the results of the study, taking into account the optimal conditions of the receiving system, the indicators are generally evaluated as follows. Bit rate in communication channels [2, 10]:

$$V_b(t, \lambda_i) = \eta_{SE}(\lambda_i) \cdot \Delta F_k, \ i = \overline{1,n}, \tag{7}$$

where $\eta_{SE}(\lambda_i)$ – spectral efficiency of the system based on wavelength λ_i based on optical DWDM technology;

ΔF_k – was the width of the inter-channel frequency interval, $\Delta F_k = 50, ..., 200 \ GHz$.

Considering the expression (6) in the formula (7), it is possible to determine the spectral efficiency of the DWDM system as

$$\eta_{SE}(\lambda_i) = N_k \cdot V_b(t, \lambda_i) \cdot (\Delta F_k)^{-1}, \ i = \overline{1,n}, \tag{8}$$

Expressions (8), in this case, in this representation, the spectral efficiency of the DWDM system depends explicitly on the bit rates and the number channels, and is also inversely proportional to the bandwidth of the optical channel.

Numerical calculations indicators fiber-optic communication lines and conclusions

Based on the results obtained, the modeling of the performance fiber-optic communication lines based on DWDM technologies in transport telecommunication systems was carried out using the Communications Toolbox package - an extension of the standard Matlab environment (R 2019b, 9.7, 64-bit), designed to calculate and simulate the characteristics communication systems.

The results obtained are included in the explicit form below. Based on the methods for calculating the value $SNR_{out.}(E_b, \lambda_i, N_0)$, it is customary to estimate for the same value $\Delta F_k = 12.5 \ GHz$, appropriate resolution optical spectrum analyzer, OSA (OSA, Optical Spectrum analyzer) $\Delta\lambda = 0.0001 mkm$ и $\lambda_i = 1.55 mkm$. For transponder without FEC (FEC, Forward Error Correction) in the format NRZ (NRZ, Non Return Zero) $OSNR_T(P_S) = 21 dB$ at $V_b(t, \lambda_i) = 10 Gbps$ and $P_{BER} = 10^{-12}$, if $OSNR_T(P_S) = 15 dB$ at $V_b(t, \lambda_i) \le 2.5 \ Gbps$ and $P_{BER} = 10^{-12} \le P_{BER}^{all.}$.[3,9,10]

The results of numerical calculations indicate that the use FEC significantly improves the situation in the system, for example, $OSNR_T(P_S) = 9 dB$ for $V_b(t, \lambda_i) = 10 Gbps$ and $OSNR_T(P_S) = 7 dB$ for $V_b(t, \lambda_i) \le 2.5 \ Gbps$.

Let's assume that $V_b(t, \lambda_i) = 12.5 \ Gbps$ and $N_k = 4, ..., 16$, then the spectral efficiency is $\eta_{SE}(\lambda_i) \ge 0.45 bps / Hz$.

Thus, as a result of the study methods and means increasing the efficiency using network and channel resources fiber-optic communication lines using dense wavelength multiplexing, a method for calculating the indicators of a DWDM system is proposed.

Based on the calculation methods, an analytical expression was obtained for estimating the line capacity of a DWDM system, the spectral efficiency modulation formats, and the probability bit errors.

Numerical calculations were carried out using methods for calculating the DWDM system throughput from the signal-to-noise ratio at the output of the communication channel for a given wavelength and the probability bit errors.

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Conflicts of interest

Author declares that there is no conflict of interest.

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